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ABSTRACT

This paper examines the oral and written discourse processes in a high school physics class and how these discourse processes are related to sociocultural practices in scientific communities. The theoretical framework is based on sociological and anthropological studies of scientific communities and ethnographies of classroom life. The use of discourse analysis as a methodological orientation in science education is reviewed and a logic-of-inquiry framing is provided to show how discourse analysis was used in the ethnographic research. The ethnographic analysis showed that, through students' participation in creating scientific papers on the physics of sound, their appropriation of scientific discourse was related to the framing activities of the teachers and the social practices established over time in the classroom. Textual analysis of the student papers focused on how they used evidence to make claims. The lessons learned from participating in the classroom of these students are explored. (Contains 80 references and 10 figures.) (PVD)

The sound of music: Experiment, discourse, and writing of science as sociocultural practices

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Abstract

In this paper we examine the oral and written discourse processes in a high school physics class and how these discourse processes are related to sociocultural practices in scientific communities. Our theoretical framework is based on sociological and anthropological studies of scientific communities and ethnographies of classroom life. We review the use of discourse analysis as a methodological orientation in science education and provide a logic-of-inquiry framing how we used discourse analysis in our ethnographic research. Our ethnographic analysis showed that, through students' participation in creating scientific papers on the physics of sound, their appropriation of scientific discourse was related to the framing activities of the teachers and the social practices established over time in the classroom. Our textual analysis of the student papers focused on how they used evidence to make claims. We explore the lessons learned from participating in the classroom of these students.

The sound of music: Experiment, discourse,
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Classroom discourse is increasingly becoming a renewed area of research in education (Gee & Green, in press; Hicks, 1995) and in science education in particular (Kelly & Green, 1997; Klaassen & Lijnse, 1996). Concurrent with this trend are increasingly more detailed and specified pictures of the workings of scientific practices studied through the multidisciplinary lens that have come to be known as science studies (Roth, McGinn, & Bowen, 1996). Sociological and anthropological studies of scientific practice and knowledge offer educators access to the discourse processes leading to scientific knowledge in the particular communities that comprise scientific fields (Kelly, Carlsen, & Cunningham, 1993). In this paper we explore discourse processes in school science through the lens of science studies and educational ethnography. Our examination of oral and written discourse in a high school physics classroom responds to the call in recent reviews for research that investigates how disciplinary knowledge is accomplished through classroom communication (Hicks, 1995; Klaassen & Lijnse, 1996).

Anthropological studies of scientific practices (Traweek, 1988; Knorr-Cetina, 1995) and ethnographies of science in schools (Lemke, 1990; Moje 1995) document the importance of studying how *what counts* as science is interactionally established by members within given communities. In this study of a high school physics class, we adapt the methodological orientation of anthropological studies of scientific practices to research how what counts as science is interactionally constructed, defined, acknowledged, and/or appropriated by members within this particular community (Kelly, Chen, & Crawford, in press). Thus, we examine school science-in-the-making (Latour, 1987), that is, the developing and evolving social processes of members of a classroom as they construct situationally defined notions of science, experiment, text, and evidence, among others.

Our perspective is derived from sociocultural theories across a variety of disciplines. Through a close examination of classroom practices we identify through the study of *social* interaction (e.g., deciding experimental protocols, interpreting inscriptions) the *cultural* practices (e.g., presenting experimental results, writing in standard genres, applying exemplars to unique problems) that constitute membership in a community. The theory underlying our work is that as members of a community (e.g., scientists in a particular field, members of a classroom) affiliate over time, they create through social interaction particular ways of talking, thinking, acting, and interacting (Green & Dixon, 1993). Thus, in order to examine how what counts as science is established in a high school physics class, we focused on the communicative processes of oral and written discourse.

The discursive processes shaping disciplinary knowledge can be taken as constructing an intellectual ecology (Toulmin, 1972) with certain norms for being a member of a community as well as norms for defining what and whose knowledge counts (Kelly & Green, 1998). From this perspective, members of an intellectual ecology create patterned ways of speaking, writing, and acting that select and privilege certain ideas and practices, and not others (Chen 1997; Crawford, Chen, & Kelly, 1997; Kelly & Crawford, 1996, 1997; Kelly & Green, 1998; Lemke, 1990). By selecting among various ideas and practices, communities--both classroom communities and communities within the disciplines of science--create a history of evolving concepts that are recognized as meaningful among members. The prominent role of discourse and interpretative processes illustrates how, through human activity, knowledge is situationally defined, thus showing the communal nature of concepts, constructs, and practices that come to count as science (Kelly, Crawford, & Green, in press; Toulmin, 1972).

In a recent review of classroom discourse, Hicks (1995) provides insights into how knowledge and practices of academic disciplines are shaped in and through the everyday talk and actions of teachers and students. Studies of classroom interaction show how discourse is a mediator for student learning (Cazden, 1988; Hicks, 1995; Mehan, 1979) and how particular teaching practices shape student opportunities for learning (Green & Dixon, 1993; Tuyay, Jennings, & Dixon, 1995). For example, classroom practices that provide students opportunities to engage in scientific ways of questioning, investigating, and knowing afford uniquely different opportunities than those that focus on disciplining students into particular semantic relationships constituting propositional knowledge (Carlsen, 1992; Lemke, 1990). Thus, what counts as disciplinary knowledge and practices of, and relevant to, a particular community can be viewed as constructed through the conventionalization and formalization of discourse processes as group members affiliate over time and build common knowledge (Edwards & Mercer, 1987; Kelly & Green, 1998).

In this paper, we review studies of scientific discourse as well as studies of discourse processes in classrooms. This review frames our analyses of the oral and written discourse processes in a high school physics class. Through examination of one genre of scientific discourse, that of an experimental article, we identify ways students used evidence in their writing. We argue that creating a scientific argument is tied to particular and situated social practices established by members of the classroom. Finally, we discuss the lessons learned from these analyses.

Viewing the communicative system of the classroom through a science studies lens

To establish the theoretical framework informing our work, we review the ways scholars of science have identified the discursive shaping of disciplinary knowledge. Our review is not comprehensive; rather, we offer some of the ways for thinking about science and discourse that influenced our analysis and writing. [For reviews of what science studies might offer science education see, Kelly, Carlsen, Cunningham, 1993; Kelly, Chen, & Crawford, in press; Millar, 1989; Roth, McGinn, & Bowen, 1996. An overview of the field of Science and Technology Studies can be found in Jasanoff, Markle, Peterson, & T. Pinch, 1995.]

In A Fragile Power: Scientists and the State, Mukerji (1989) examined how scientists negotiate away aspects of their intellectual authority in the processes of trying to maintain intellectual autonomy while being fiscally dependent on state funding agencies. To accomplish the work of doing their research, the scientists in this study (oceanographers) needed to partially turn over their autonomy and participate in the complex social world of making science function as an institution with sets of intradisciplinary and interdisciplinary rivalries that enter into the negotiations of creating viable mechanisms and contexts for doing research. In particular, oceanographers and other scientists need to engage in various forms of discourse tempered and mediated appropriately to given audiences. In examining how scientific discourse is directed, Mukerji identified a broad range of discursive processes necessary for scientists to be successful: Scientists provide expertise to the state in ways that maintained their credibility without trivializing the complexities of the topical debates in a given field; they need to find ways to change the substance of a scientific debate to direct the "need" to their line of work; they often discredit rival social groups that compete for the same research funding and geographical space; they read and write to journals with specialized and stylized discourse procedures; they present their science to the mass media; they use persuasion to recruit materials and personnel to their particular laboratories and projects; and they find ways to collaborate with colleagues, both within and across disciplines.

Through an examination of the actual processes of doing science and ways scientists talked about doing science, Mukerji described a range of discourse processes in scientific communities. Thus, to consider the "discourse of science" we need to consider the range of social, political, and technical aspects of the various discourses of science. Some of these discourse processes are explicitly political and involve positioning within social groups. These and other discourse processes are ideological in the sense that they form sets of values and viewpoints that are not always stated (Gee, 1990). For the case of oceanographers, both oral and written discourses are used across a variety of contexts and purposes. However, while the final products of science can only be achieved through a variety of discourses drawing from the social and political dimensions of scientists' repertoires, these final products are typically represented in written forms following the restraints of particular genres. The production of the written texts of science are thus the result of multiple discourses that include, for example, recruiting expertise to a particular laboratory, using citations to form alliances, and positioning authors in the rivalries found at the forefront of science. Mukerji found that thinking of and about science for oceanographers, and scientists more generally, was a "highly literate activity:"

> But what distinguishes science and has helped to make it grow in the West is the use of documents--records of experiment, expeditions, and other studies--and reflection on these records that result in written journal articles and other papers. The science used to formulate policy is developed from written words, numbers, graphs, and pictures registered on paper in scientific labs. (p. 199-200)

Mukerji's study of the processes and products of oceanographers show the two faces of science identified by Latour (1987), ready-made science (science in its compressed, formalized, abstracted forms of product) and science-in-the-making (science as it is being brought into existence with social, experimental, and epistemological contingencies). We now turn to the rhetorical form of formalized scientific writing and the sociocultural conditions that shape the construction of these texts.

In Shaping Written Knowledge, Bazerman (1988) examined the genre of the experimental research article as a cultural form. Through a series of textual analyses, Bazerman identified restraints made on the demands for communication over the history of writing in science. For example, the agnostic forum of the experimental journal article can be seen as a response to the rhetorical demands of the scientific communities that have evolved over time. This historical view suggests that knowledge is entered into science through the use of persuasion and survives through the communication systems and lived practices of the respective communities. As suggested by Toulmin (1972), Bazerman views these communities as having particular conventionalized practices that shape the relationships of text and audience, making persuasion "a lengthy process of negotiation, transformation, and growth of the central formulations and related arguments" (p. 309).

Communication presupposes shared knowledge and Bazerman offered two kinds of situations where this knowledge may be examined: the neophyte becoming familiar with the shared knowledge of the community and the establishment or re-establishment of the shared understanding in times of change, growth, or instability. Bazerman explained the first situation, drawing from a Vygotskian perspective. He identified how through processes of participation and scaffolding "gradually the neophyte becomes socialized into the semiotic-behavioral-perceptual system of a community with language taking a major and multivalent role in the organization of that system" (p. 307). As in the study by Mukerji, Bazerman pointed to the commitment of scientists to new formulations, new knowledge and how such contributions must be understood as promising to be more useful or productive for the relevant community. Proposers of new knowledge must be willing to hold their assertions up to public scrutiny. By entering their ideas into the nexus of discourses, behaviors, and formulations, these candidates for knowledge may come to count as, or be rejected, as science through dialogical and dialectical processes.

To understand how the multiple discourse practices among members of and within scientific communities lead to legitimated knowledge in the compressed and compact form of the experimental article, we review Latour's (1987) analysis of the processes of fact production. While science is often entered into schools in its ready-made form (e.g., in the written form of textbooks), the sociological processes leading to such formulations need to be examined. By studying science-in-the-making Latour investigated ways scientists seek to establish assertions as facts. This fact production of the particular communities occurs during periods of instability in the shared knowledge, the second situation identified by Bazerman.

Latour analyzed how scientists position themselves and others in their written texts by "bringing in friends" through citation and by using other texts in strategic ways. Latour identified one goal of scientific text production as the generation of high inference claims (e.g., about the properties of mammal countercurrent structure in the kidney) rather than highly contingent, qualified claims referring to particulars (e.g., slices of flesh in a particular laboratory). Thus, in the process of fact producing, scientists seek to establish facts about constructs like kidney structure from a body of evidence that starts with "slices of flesh." Pictures, figures, numbers, and inscriptions of other sorts can be used by authors to fortify their claims. However, these are potentially dangerous as they also provide readers (particularly critics) ways to unravel the highly generalized assertions to a set of contingent, highly problematic, and perhaps isolated facts about particular physical entities. Thus, the rhetorical demands on scientists include ways of moving from the contingencies of science-in-the-making into the concretized facts that come to be presented as ready-made science.

These three studies by Mukerji, Bazerman, and Latour show the range of discourses employed in the construction of scientific knowledge and expertise, the role written texts play in shaping what counts as knowledge, and the rhetorical and textual strategies of producing facts in science. Other studies of scientific knowledge and practices identified still other means, uses, and purposes of oral and written discourse. For example, discourse processes in scientific communities have been shown to determine and shape the nature of scientific knowledge, including generating and interpreting inscriptions (Latour & Woolgar, 1986), creating discovery accounts (Brannigan, 1981; Woolgar, 1980), forming arguments about experiments and institutional rivals (Gilbert & Mulkay, 1984), and creating experimental contexts that create the need for science (Pinch, 1986). These studies suggest that those considering of science and discourse in schools needs to examine how science is invoked, appropriated, positioned, understood, and taken up by participants. From a research perspective, the treatment of the "discourse of science" as a unified notion is potentially problematic.

Discourse processes in science education

Discourse processes, both oral and written, have become the subject of study among educational researchers concerned with the ways such processes support or constrain access to scientific knowledge (Crawford & Chen, 1997; Kelly & Crawford, 1997), the ways science is presented to and positioned for students (Moje, 1995; Lemke 1988, 1990), the ways students can be seen as constructing knowledge (Roth & Lucas, 1997), the ways arguments are made (Kelly, Druker, & Chen, in press), and the ways authority is invoked (Carlsen, 1997), among others. As our review of science studies showed that scientific practices are "highly literate" activities involving both oral and written discourse, we begin by reviewing research in science and writing and then situate this research in a larger field concerned with discourse processes more generally.

A recent review of writing in secondary science by Prain and Hand (1996) considered a variety of issues involved in writing science in schools, including conceptions of the purposes of science education and conceptions and perspectives on language from modernist and postmodernist perspectives. In this review the authors explored the tensions among those who advocate initiating students into the current discourse practices of science, and those, following constructivist perspectives, who advocate a consideration of students' personal understandings and explorations through writing, as well as those postmodernists advocating border crossings and mixed genres. Prain and Hand demonstrated through this review that there are a wide variety of prescriptions for the use of writing in science and that there is considerable disagreement about the purposes of learning science, a view evident in a recent Special Issue of the Journal of Research in Science Teaching focused on the reading-science learning-writing connection (Yore, Holliday, & Alvermann, 1994). However, the model offered by Prain and Hand (1996) suggested a multiplicity of genres and purposes for using writing so that students can understand how to write and critique current representations in and of science. The model they advocate offers five types of elements for writing to learn in science: "writing types; writing purposes; audience or readership; topic structure including concept clusters; and method of text production, including how drafts are produced both in terms of the technologies used as well as variations between individual and composite authorship processes" (p. 618).

Our review of science and discourse suggested that the production of written texts was the consequence of particular social actions and oral discourse processes. Thus, written discourses represent only some of the interconnected discourse processes of classroom life. We therefore need to consider the range of discourse processes shaping science in schools. Studies of classroom interaction in science have focused on the ways that science and authority are shaped by teacher through oral discourse, although there is a growing body of work that examines student discourse, particularly in small groups settings (Bianchini, 1997; Finkel, 1996; Kelly & Crawford, 1996, Richmond & Striley, 1996; Roth, 1996). We will consider both here. Discourse analysis centered on the ways teachers shape disciplinary knowledge paint a picture of classroom interaction that is considerably less multidimensional than the activities of scientists identified in science studies. Carlsen (1991, 1992) showed that insufficient subject matter knowledge led teachers to control classroom conversations by privileging facts rather than treating concepts in a dialogic and interactive manner. When they were talking about an area that was less familiar, these teachers generally stayed closer to the textbook inscription by orally reproducing what was written as science. They were also more likely to ask factual, rather than provocative, questions, thus invoking the authority of scientific facts. In a later study, Carlsen (1997) took on the role of teacher and analyzed his own classroom discourse. When teaching an area of science in which the teacher had practical and academic knowledge (biology), he entertained and asked more complex questions, than when teaching a subject in which he had less background knowledge (chemistry). Through the examination of his discourse processes from an argumentation perspective, he found that his own arguments were more philosophically problematic when teaching the less familiar subject matter.

Lemke (1990) showed that through particular discourse practices teachers invoked the authority of science in an ideological manner by focusing on the propositional knowledge of the subject matter without providing the relevant theoretical backing and justification. He suggested that the processes of learning science are connected to the learners' understanding of the genres, formats for reasoning, speaking, and writing in the community that constitutes the discipline of study. However, unlike the studies by Mukerji and other sociologists and anthropologists of science, the teachers in Lemke's studies conceived of and evoked the discourse of science in narrow ways, focusing mainly on the semantic relationships that form the theoretical knowledge of ready-made science. Thus, science was presented to students in its compressed, dense forms, making it less readily accessible to students. Through these discourse processes, the teachers positioned science as a discipline in particular ways that included a distorted view of the methods of knowledge construction (see also Moje, 1995). The resulting portrayal created a "mystique of science" that ideologically represented science as particularly authoritative and difficult. Lemke's (1990) studies of science classrooms led him to suggest that students should be offered opportunities to talk science in a variety of contexts. One approach to providing students such opportunities is the use of group work that allows students to conduct experiments in social situations where they are expected to articulate their ideas.

While many studies show that discourse practices of teachers shape the views of science made available in schools, little is known about the extent to which students take up these views or how these views change the concepts held by students. However, recently a series of studies focused on student discourse has emerged aimed at understanding group processes. This research on small group work shows that access to scientific discourse processes varies both within, and certainty across settings and contexts. By focusing on the student discourse in small group settings researchers are beginning to get a picture of the complexities of achieving normative goals sought by educators (e.g., uses of evidence, consideration of others' points of view). These studies document the ways students interact, provide initial insights into students' appropriation and use of scientific discourse, and identify the problematic nature of small group interaction.

In a series of studies, researchers Warren, Roseberry, and Conant (1994, 1995) offered a view of classroom communities quite different than those studied by Lemke (1990). Working with teachers and students, these researchers based their work on a view of science dependent on argumentation and persuasion, a view informed by science studies. Warren, Roseberry, and Conant (1995) included in their goals the creation of classroom communities "in which students appropriate the discourse of science: a set of sociohistorically constituted practices for constructing facts, for integrating facts into explanations, for defending and challenging claims, for interpreting evidence, for using and developing models, for transforming observations into findings, for arguing theories" (p. 5). Through these processes, learning science is conceived of as "the appropriation of a particular way of making sense of the world: of conceptualizing, evaluating, and representing the world" (p. 5). The authors (1994, 1995) provided examples of students working on meaningful problems (e.g., assessing water quality through sampling of pond, home, and school sources; snails in aquatic environments) for which they are able to engage in the discourse processes of scientific practices, not unlike those described by Latour and Woolgar (1986).

The heterogeneous nature of access to scientific discourse has been documented in a series of studies focused on student discourse. Bianchini (1997) studied a middle school science course that employed Complex Instruction (a model of groupwork) as an instructional strategy for learning human biology. Through research interviewing, videotape analysis of student discourse, and quantitative analyses, this study examined the relationship of student status, participation patterns, and their relationship to science learning. Drawing from examples of student discourse, Bianchini found that even under the specified conditions of Complex Instruction, students often strayed from the curricular goal of talking science and sought to accomplish other goals such as social positioning. Variations in the construction of school science were also identified in an ethnographic study by Kelly & Crawford (1997). In this study of a multigrade conceptual physics course, access to the social practices of the classroom varied across student groups. Specifically, one student group under study entered their classmate into the discourse processes of the class, drawing on their knowledge of physics from a previous class, while another student group ignored a new member, limiting what she could understand about the physics of the lesson. Richmond and Striley (1996) analyzed students' use of arguments in tenth-grade integrated science and found that while students made strides toward improved use of argumentation, these results similarly varied across student groups. The differential opportunities to learn science were constructed in part by the emergence of the social roles of the student group members. In particular, the groups' leadership roles were analyzed in detail showing how student group leaders shaped the construction of knowledge through their role of mediator and distributor of talk.

Across subject matter, grade level, and topic, these studies, while generally favorable to the potential of small group work, suggest that a close examination of the relationships of the established practices of classroom life with the processes and products of student work need further investigation. Such investigations posed methodological challenges, such as the interactive effects of recording equipment, the difficulties associated with producing retrievable data of high sound quality, the ethical issues associated with such close examinations of human interaction, the need for long term data in order to situate discourse processes events in the patterned activity of the members of the classroom, among others. We begin to address these challenges by describing our choice of research site, and level and role of researcher participation.

Educational Setting

The overall ethnographic research project from which this study was conducted spanned three academic years. The study took place in a Conceptual Physics (Hewitt, 1992) course at a public high school in southern California. The first two academic years were co-taught by the first author. The data analyzed for this paper were collected mid-term in year two by our research team, which consisted of a university professor and two graduate assistants (see Chen, 1997; Crawford, Chen, & Kelly, 1997; Kelly & Crawford, 1997). Besides the co-teaching by a university researcher, structural features made this course unique. The course was populated by students from all four years of high school (9th through 12th grade) and met 90 minutes a day, 5 days a week. The school is situated geographically between two small cities and draws students from a wide range socioeconomic backgrounds. The ethnic background of the school is approximately 50% "white", 44% "Hispanic", with much smaller percentages from "black", "Asian/Pacific Islander", and "American Indian" populations. [These ethnic/cultural/racial terms are taken from the school's records and are thus "folk" terms (Spradley, 1980)]. However, representation in the physics course did not reflect these school percentages. In year two, the ethnic breakdown was as follows: 61% White, 29% Hispanic and 10% Asian/Pacific Islander. The gender distribution was 51% male and 49% female, consistent with roughly equally numbers of male and female students throughout the three academic years.

This conceptual physics course was the site for a number of pedagogical innovations over the course of the three-academic-year project. For example, students used microcomputers to acquire and analyze data, search for historical and technical information on the Internet, and write technical papers. Working in collaborative teams, students spent

2-4 weeks designing, testing, refining, and presenting scientific projects of their own choosing, such as functional mechanical and thermodynamic devices.

The rationale for our choice of participation as participant-observers was derived from ethical, epistemological and pedagogical considerations. The first author chose to be co-teacher of the course to get a close look and develop relationships with the classroom teacher and students; to offer labor to the processes of reconstructing the physics course; to provide teaching assistance and support for student learning; and to use his and his fellow researchers' observations to make suggestions for improving the course. The choice was strategic from a research point of view as, through his role as teacher/researcher, the first author had a reason to be in the conversations that the classroom teacher and students were having of and about science. In addition, we sought to put the researchers literally and metaphorically "in front of" as well as "behind" the video cameras. Rather than conducting research on a teacher and critiquing her or his methods in a judgmental manner, as is so often and easily done to other's teaching methods as noted in a recent editorial (Abell & Flick, 1997), we sought to balance the scrutiny on both the researcher and teacher. Thus, our choice of participation was partially aimed at creating a model of classroom research that disturbed the roles of the researcher as theorist and teacher as practitioner, with the former judging the quality of the latter [for studies with similar methodological and participation strategies see studies by Roth, 1995 and Carlsen, 1997] . This choice raises a number of problems, however, not the least of which is the documentation and interpretation of the range of activities in the classroom.

In order to capture the classroom interactions, we included in our research team graduate student ethnographers who made daily observations, recorded written fieldnotes, operated the video equipment, and conducted informal interviews (Spradley, 1980). Data were gathered from multiple sources over the entire ethnography, including videotaped records (lectures, group work, and presentations), student artifacts (written assignments, exhibit displays), ethnographic interviews (Spradley, 1979) and fieldnotes [for related studies see Chen, 1997; Crawford, Chen, & Kelly, 1997; Kelly & Crawford, 1997; Kelly, Druker, & Chen, in press.]

Methods and Analyses

Our study of the oral and written discourse processes of a cycle of activity--an interactionally bound sets of lessons and activities centered around a specific theme (Green & Meyer, 1991)--is based on an ethnographic approach to researching human activity (Spradley, 1980). This approach focuses on examining cultural actions, artifacts, and discourse processes through which group members construct social situations. Spradley's ethnographic research cycle suggests a gradual change in the scope of ethnographic observations, from descriptive to focused, and finally, to selective observations. Thus, over the course of our analyses, we "zoomed in" to look at specific actions and "zoomed out" to look across groups and over time.

Our analysis sought to identify the ties among classroom practices. We began at a general level of observation, and through a set of questions posed as part of the Ethnographic Research Cycle, gradually focused to how patterns of activity were accomplished through discourse (Kelly, Crawford, & Green in review). The Ethnographic Research Cycle consists of asking questions, collecting data, making an ethnographic record, and analyzing these data, through multiple iterative cycles (Spradley, 1980, p. 29). This iterative research process enabled us to examine a range of cultural practices and to explore how these practices, in turn, shaped what was interactionally accomplished. Thus, in the section that follows, we describe our research methods as we unfold the logic-of-inquiry (Gee & Green, in press) that led us to both our initial interpretations and our next step in analysis. In this way, the later research methods, derived from both questions previously posed and initial interpretations, were contingent on previous iterations of the research cycle. The oral and written discourse processes of the teachers and students examined in this study, the types and range of data sources, and the types of analyses, are presented schematically in Figure 1. This cognitive map shows how the research processes of the ethnographic research cycle include cycles of focusing to specific events and of situating these events in broader social actions. Our logic-of-inquiry can be traced through this representation.

Identifying and investigating a "cycle of activity"

After collecting our ethnographic data, one of the first interpretive decisions made was the choice of a unit of analyses. Since the ethnographic data include videotape records that span three academic years, we were not able to conduct a discourse analysis of all the oral and written language used in the classroom. Rather, we had to make selection decisions about what and how to represent our data. Green and Meyer (1991) use the term "cycle of activity" to denote a set of intercontextually-tied activities initiated, enacted, and bound interactively by the participants with common thematic content (Floriani, 1993). We decided to consider a two week cycle of activity concerning the study of wave motion. This choice was based on our initial ethnographic information and experience through which we identified a key discourse event, the cumulative discourse activity of writing a scientific paper. The scientific paper was part of a teacher-assigned student project in which students designed, built, and tested musical instruments of their choosing.

The cycle of activity, analytically named "physics of sound," spanned two weeks (11/06/95-11/21/95) and was embedded in the larger classroom history and ethnographic study (see Figure 2). Events and topics listed on the timeline were specific to the thematic content of the physics of sound. Topics involved in and comprising the cycle of activity in the class during this time included: Simple harmonic motion (lecture, pendulum lab); wave theory (lecture, film, demonstrations); graphing wave forms (lecture; labs); sound (lectures, sound labs: tuning fork & human voice; consonants & vowels; fundamentals & harmonics); light (e.g., Optics lab); and the musical instruments project. As shown in Figure 2, there were a range of instructional strategies (e.g., lectures, discussions, demonstrations, groupwork, use of media, laboratory experiments, presentations by students to class), and interactional spaces (Heras, 1993) (e.g., whole class, small groups). Two key events (Gumperz, 1982) within the cycle of activity were noted as important as they framed the events that counted as the cumulative task for the cycle of activity: the production of a musical instrument; and a corresponding technical paper, written to describe the experiments conducted with the instrument.

The next level of analysis involved creating structuration maps of the moment-to-moment interactions of the participants for each of the days in the cycle of activity. These maps were created by identifying the ways that the members of the classroom oriented to the topics and each other, and by noting the episodic nature of the instructional conversations marked interactionally by the members of the classroom (Green & Wallet, 1981; Lemke, 1990; Mehan, 1979). Following a methodology developed by Green and her colleagues (Green & Dixon, 1993; Green & Meyer, 1991; Green & Wallet, 1981), we identified the different phases of activity for each event on each day. Phases of activity representing the ebb and flow concerted and coordinated action among participants and reflecting a common content focus of the group were identified by examining the actors' talk. For example, the phase unit labeled "Introduction of Musical Instrument Project" is written in bold on Figure 2 and is the third of the four phases of activity comprising the class of 11/15/95. Within each phase, the participants structure the conversations and cue each other through their interactions by marking cohesive or thematically-tied interactions to form a sequence unit. For example, the sequence units comprising the phase unit "Introduction of Musical Instrument Project" are represented in Figure 3.

The sequencing of the talk and actions represented in Figure 3 show how through a set of discourse processes this teacher/researcher (first author) constructed a lecture that came to be an "introduction of musical instruments project." In this case, the lecture began with a sequence labeled "passing out project instructions." This is one of many examples of how the oral discourse reinforced and was connected to written discourse. Analytically, this signaled to us the importance of both discourse forms and led us to consider both in subsequent analysis. For example, the relationship between oral and written texts in a subsequent event was visible when we examined the developing activity across sequence units. For the case represented in Figure 3 the lecture proceeded through a series of steps that oriented the students to the project in a particular way. After offering a rationale for the sequencing of the curriculum (sequence starting at 00:56:38) the teacher introduced the first suggested activity: The student groups were instructed to keep a record of their activities. As is often the case, the sequence labels were not sufficiently descriptive to be analytically exhaustive, we therefore included a record of notes and comments.

Discursively accomplished nature of everyday life

The analysis of the classroom interactions at the phase and sequence level allowed us to identify a range of discourse processes, how these processes were connected with thematic development, and how particular events framed later events that occurred within the same cycle of activity (see Floriani, 1993, for a related discussion of intercontextuality). Our ethnographic analysis showed that the musical instrument project consisted of a practical component (e.g., instrument design, testing, analysis of data) and a written component (e.g., writing of a technical paper). Our theoretical position suggests that the framing of these events occurred discursively through the moment-to-moment interactions. Therefore, the next step in our analysis was to examine the ways that the events sequenced in the structuration maps were spoken and acted by the participants. To do this, we created transcripts of the talk and action for selected sequence units, following theoretical sampling procedures: That is, we chose to sample those events that were signaled among the participants as important for accomplishing the tasks.

The transcripts were created in message and action units. Messages units are the smallest unit of linguistic meaning (Bloome & Egan-Robertson, 1993; Green & Wallat; 1981; Kelly & Crawford, 1996), defined by boundaries of utterances or social action that are identified through cues to contextualization, e.g., pitch, stress, intonation, pause structures, physical orientation, proxemic distance, and eye gaze (Gumperz, 1992). This was done directly from the videotape as the non-verbal cues are important in identifying the message units. Action units are comprised of one or more message units that show a semantic relationship among message units, and represent an observed intended act by a speaker (Kelly & Crawford, 1996). Action units, like message units, are identified *post hoc*, and as researchers, we again considered the contextualization cues as well as the topical content of the talk. For the transcripts in this paper, message units are demarcated by line number and action units are marked by spaces in the transcript.

Figure 3 shows that during the teacher/researcher's exposition about student record keeping (starting at time 00:56:56) there was an interruption (at time 00:57:10), involving student concerns about the time constraints of the proposed plan for the project, which we labeled as a potential divergence (following Green & Wallet, 1981). At 00:58:49, the teacher/researcher (TR) reoriented the topic to the keeping of records and then started a series of sequence units referring directly to the musical instrument project. These sequences were transcribed verbatim with researcher notes in italics as represented in Figure 4. In line 107 (see Figure 4) the teacher/researcher took back the floor from the classroom teacher and began a series of instructions emphasizing components of the students' musical instrument projects. This emphasis centered around the teachers' instructions for the thematic and social aspects of the intended procedures and goals. The students were instructed to: use outside resources e.g., the Internet and library (lines 108-110) as they had done in a previous thematic project, i.e., the solar energy project (lines 114-115); build an instrument as a group (lines 117-119) in cooperation with the members of each small group (lines 120-123); and use relatively simple materials (lines 124-132). In a second series of assertions the teacher/researcher emphasized some of the epistemological goals through another set of instructions. The students were instructed to: conduct experiments with the microcomputer that produces graphs (lines 134-142), vary the parameters of the instruments (lines 149-158), and conduct others experiments for comparison (line 159). This ended the sequence unit labeled "Changing the instrument." The teacher/researcher foreshadowed a discussion of the writing aspects of the project (starting at 01:01:20), answered a student question about "extra credit," and summarized the project tasks.

The subsequent sequence was initiated by the classroom teacher (CT). Through our examination of the transcript of teacher discourse for this sequence we were able to identify the shift in the presentations of the teachers' expectations about the project. The classroom teacher constructed, and was constructed as having, the role of organizer and manager of the classroom activities. This was evident in his talk (see Figure 5). The teacher referenced time or due dates seven times, e.g., "there's not/a lot of time" (lines 204-206), "it a be due/on next/Tuesday" (lines 236-238), "so let's/let's/look at/go to the time table" (lines 266-269). In addition, he repeated the steps of the project reinforcing the description of the teacher/researcher: "select an instrument" (line 217), "build it/or make it" (lines 219-229) "test it out" (line 223) and "write a paper about it" (line 226). He ended this sequence by suggesting particular strategies for "the first order of business" (line 279), i.e., a way for students to get started on their projects, including meeting in the respective groups and discussing ideas. The role of time manager again surfaced as he instructed the students that they "don't have to to any searching/in the library or internet" (lines 289-290) if the groups had "an idea already," and by suggesting that they take "5 or 6 minutes or maybe 10 minutes" (lines 303-304) to complete these tasks. Our examination of the particular ways the teacher/researcher and classroom teacher talked about the musical instrument project tasks revealed differences in their roles and responsibilities to the students and school. The tension between completing a "scientific" paper and completing a "school" task resurfaced later in the ethnographic analysis of the events.

<u>Written texts as framing artifacts</u>

In order to understand how the writing of the technical paper was situated in the over-time practices of the classroom, we examined how the task was constructed by teachers and students and how this particular genre of writing was one of the kinds of writing sanctioned in the conceptual physics course. Before presenting our analysis of how framing activities and texts came to define the technical paper, we identified the range of writing activities that were sanctioned in the course through taxonomic analysis (Spradley, 1980), presented in Figure 6. We classified the particular writing activities into four groups: classwork and assignments, creative writing, presentation of science through class thematic projects, and essays about the physics course. The writing activities found within each of these groups showed a range of writing genres with varying topics, purposes, types, audiences, and methods of production (c.f., the expanded model of elements for writing to learn in science, proposed by Prain and Hand (1996)). For example, students recorded notes from teacher lectures with accompanying overhead projection slides in their notebooks; they wrote a science fiction story about time travel; and they proposed ways for improving the teaching of the course. For the musical instruments' project, the writing of the technical paper was one of two elements for writing to learn in science, as in addition to this task, the students were instructed to record their activities while they created their musical instruments. Although all students wrote the technical paper, we have little evidence that students completed the record keeping task.

The school science task of writing a technical paper was modeled after a university science course that incorporates the writing of scientific papers as a central feature of instruction. For this university course, the professor created a text describing "how to write a technical paper," that served as a basis for instructions to the students. We modified the instructions prepared for the university students and created a simplified version for the high school conceptual physics students, while maintaining the substantive components of the original text.

Through our ethnographic analysis we identified a key event on 11/16/95 in the cycle of activity that is labeled on Figure 2 as "Introduction to Writing Technical Papers." In this event the teacher/researcher talked through the modified instruction sheet about how to write a technical paper. Figure 7 shows the juxtaposition of the oral and written discourse about the writing of these papers. The left hand column is the set of discourse processes of the teacher/researcher as he walked and talked the students through the main elements of the written instructions presented in the right hand column. For analytical purposes, we have kept both the oral and written discourse in the sequences in which it was presented to the students, but in Figure 7 we have aligned the ways the teacher/researcher spoke about the issues with the writing text. Thus, the line numbers in this case do not refer to message units nor lines in the written document; they label the utterances and lines of texts for discussion purposes.

The written instruction was comprised of four sections: orientation; general writing tips; presentation; and headings, including six subtopics, introduction, methods, observations, interpretation, conclusions, and using figures. However, these sections and subsections were not treated equally by the teacher/researcher as he reviewed the issues. We can read the left hand column of teacher discourse as a way of signaling to the students emphasis on certain issues and not others. In both the oral and written discourse, the students are provided with a rationale for writing in science (lines 400-413). The written discourse mentioned audience and the uses of writing in science (lines 400-405), while the oral discourse used contrasts with fiction and biography to make distinctions about writing in science (lines 405, 410-411). The next section in the written section concerning "General writing tips" referred to the mechanics and regulations of writing in science. This section was given only a brief mention and the students were told that "you can read through that" (line 417). The next section on "presentation" showed contrasts in the instructions, with the oral discourse qualifying the need for the papers to be "clearly typed or clearly hand written and thoroughly proofread" (lines 434-436 or written discourse) by suggesting that the students "can either type it [the paper] or handwrite is neat (enough), either way is OK" (lines 435-438).

The section labeled "Headings" (line 440) described a format for the papers and in doing so epistemologically positioned the students as writers, technical writing as a genre, and science as a discipline. There were five types of headings (introduction, methods, observations, interpretation, and conclusion) as well as a discussion of professional ethics (lines 476-479) and use of figures. As a comprehensive discourse analysis of the written and oral forms is not possible here, we will review how the section on interpretation was written and talked into being (Green & Dixon, 1993; Tuyay, Jennings, & Dixon, 1995). The interpretation section of the written discourse suggested the use of observations and an explicit invocation of personal "experience, insight, and knowledge" (lines 469-471) to explain these observations and to "reason with evidence" (line 473). Emphasis on these issues was similarly evoked in the oral discourse, although in different ways. The teacher/researcher referenced a previous discussion about performing "tests" on the musical instruments to create data in the form of printed inscriptions (lines 466-468). Interpretation and its relationship with data and figures was explicitly mentioned in lines 473-484. In this section, the students were instructed that their interpretation was to "discuss what the data means [sic]" and offered the suggestion of referring to their "waveform"--an inscription representing pressure-time relationship (see subsequent discussion). In this case, the teacher/researcher gave further specification by suggesting a possible relationship, that of "frequency/how that's related to pitch/how it's related to the change in your/um/your modification of your instrument" (lines 480-482). Thus, in both the written and oral discourse processes the importance of interpretation was signaled to the students. In both cases, the uses of data were invoked; in the case of the oral discourse, this was connected to the uses of figures--a point described subsequently in the written discourse (lines 485-496). The written description of interpretation suggested personal creativity, but pointed to the use of reasoned evidence as "important." This was later suggested as the "main idea" and linked to interpretation in the oral discourse: "And the main idea now is that you're going to be using the data you collect in class and use that as evidence for your interpretations" (lines 490-493).

The comparison of oral and written discourse showed how certain aspects of the written text were emphasized and how, in the range of epistemological issues, certain interpretations were related to the particular tasks of the musical instrument project. These texts provided a framing for the students of what was to count as scientific practices in this cycle of activity. Consistent with the ethnographic research cycle, we used this analysis to pose a number of questions about how the student chose to engage in the practices signaled through the teachers' discourses. Did the students follow the suggestions of the writing genre recommended to them? In what ways were they reading these discourses and incorporating them into their own writing? How did they use evidence and in what ways? Before turning to the examination of the students' technical papers, we review further the physics of the experimentation suggested to the students.

The physics of the sound project: Material and semiotic considerations

Figure 8 shows the inscription of a sound wave, represented on the axes Sound (pressure) versus Time (ms), and recorded through the Vernier software interface and software package entitled "Sound." This particular sound wave represents the sound of a commercially produced recorder. Even with an instrument of this tonal quality, the graph shows that there are a number of contingencies that make the decisions about what counts as a periodic wave and what the periodicity might be, as well as what counts as the amplitude of the wave, among other aspects, interpretive. For example, observers such as the high school physics students are faced with a set of problematic decisions to make: if there is periodicity, are there three peaks to a period or one? How would one know and decide what counts as a time period for a sound wave? In addition, the hypertext overlay is the computer's representation of the Fast Fourier Transform (FFT). This analysis, plotted as amplitude (pressure) versus FFT of sound (data A), shows how the respective wave form is comprised of a fundamental frequency and a set of harmonics. In this case the arrow points to the fundamental and the computer reports a frequency range of 428-442 Hz. The harmonics occur at roughly equal intervals, in this case we can interpret the peak reported to be in the interval range of 864-877 Hz and the peak reported as 1299-1312 Hz to be harmonics. There are four others peaks that require further explanation.

This type of analysis was introduced to the students through two lectures as noted on Figure 2 as "wave lecture" and "FFT (Fast Fourier Transform) lecture with demonstration," and three preparatory laboratory experiences labeled "sound lab: tuning fork and voice," "sound lab: consonants and vowels," and "sound lab: fundamental and harmonics." These experiences were part of students' preparation for using the recording equipment and programs, observing the waveforms and Fourier transform peaks, and drawing inferences. However, the complexities of the experiments and their interpretation depended on a number of contingencies, including the types of sound waves recorded and the extent to which explanation was sought. Therefore, the task facing the student groups for the analysis of their musical instrument was at once relatively simple (i.e., record a sound and interpret the computer representations) and simultaneously very sophisticated. The problem space does not have clear limits; the students could have explored a range of possibilities such as amplitude and frequency variation (which many did), error ranges (as one did), and the theory of Fourier transform (which none did).

<u>Analysis of student products: Appropriation of scientific discourse--technical paper as artifact</u>

Our next analyses concerned the student technical papers. From the ethnographic point of view, these were treated as artifacts, produced by a community under certain conditions for particular purposes. The logic-of-inquiry for our analysis of the students' writing of the technical papers was as follows. First, we entered each of the students' papers into a computer file, creating a "case" for each. Second, for each paper, we proceeded to consider the central arguments that the authors were making. This provided us with a holistic view of what the students were arguing in their writing and what was being accomplished through their writing.

Third, because the teachers indicated through both oral and written discourse the importance of the use of evidence as a central goal of the writing task, this led us to consider how the students were using evidence in their papers. To specify the arguments, we applied an argumentation analysis developed previously (Kelly, Druker, & Chen, in press; Druker, Chen, & Kelly, 1997) following the Toulmin model (1958). Toulmin's layout of substantive arguments involves the warranting of a move from data to claims. He characterized the components of the argument as follows: Data (D) are the facts the proponent of the argument explicitly appeals to as a foundation for the claim. The claim (C) is the conclusion whose merits are sought to establish. The warrant (W) is the rules, principles, or inference license that demonstrate that the step to the claim from the data is a legitimate one. The strength of the warrant may be indicated by modal qualifiers (Q). The rebuttal (R) indicates the circumstances for which the general authority of the warrant is not merited. The backing (B) establishes the general conditions which give authority to the warrants. We used this general structure to consider the claims and supporting evidence (combination of data and warrants) in the students' papers. All claims referring to substantive issues and corresponding evidence were identified through this analytic procedure.

Fourth, we considered only the evidenced claims and marked these claims and the evidence supporting them. As was found in Kelly, Druker, & Chen (in press), not all claims in a discourse event will typically be supported with evidence. This should not be alarming, even for writing in science. At the propositional level, support for each and every assertion would lead to infinite regress, or at least regress to first principle in each case.

Fifth, we jointly reviewed the evidenced claims and inductively generated a taxonomy of "kinds of claims" and "kinds of evidence." We did this through multiple iterations of reviewing the data until we reached mutual agreements on each case.

Sixth, following Latour (1987), we then considered the status of the claims. Latour argued that scientists typically argue from the particular contingencies of their actual experiments and try to construct facts at a more generalized level. In this way they "stack" the facts, moving from "low induction" facts using the pictures, figures, and numbers to progressively higher induction, more abstract facts. According to Latour the trick is to stack facts so that there are no gaps between layers that provide ways to unravel the arguments. In order to consider the facts presented in the students' papers, we reviewed all the kinds of claims and kinds of evidence and created two "stacks" shown in Figures 9 and 10, with illustrative examples. Through examination of these stacks and the respective distribution of kinds of claims and evidence, we began to get a picture of the students' use of evidence.

Seventh, we created Table 1 showing the distribution of evidenced claims across technical paper subject headings suggested by the teachers. Five students did not follow the heading format and, although we included their papers in all other analyses, we did not consider the position of their claims in the paper for the creation of this distribution. The merits of their scientific arguments were viewed negatively because of their formatting choice.

Our analysis of the claims and evidence presented in the students' papers revealed a partial engagement with the intended task. The students generally followed the particular scientific genre presented to them; they made a large set of claims, supported some of these claims with evidence, and used the data inscriptions as figures in their papers. Figure 9 shows that there was a broad range in the types of claims made by the students, from low induction claims about observations of their instruments (e.g., "We had four different drums, all of different sizes, to make a variance of noises") to claims that tied the inscriptions (e.g., "large spikes, medium peaks, and small waves") to constructs in physics such as frequency. The claim types with the highest frequency were those that involved physics constructs such as a harmonic frequency, tension, sound pitches, and amplitude. However, there were also claims referring to specific measured values, aspects of the instruments, and relationships among aspects of the representations. Two kinds of evidenced claims were not included in the stack, those commenting on the projects, and those addressing the section headings of the technical paper (see Figure 9 bottom) as as they were of a different sort unrelated to the analysis.

An examination of where the students chose to make their evidenced claims partially reveals how they understood the task of creating arguments with observations and interpretations. As suggested in the teacher discourse, the referential and explanatory aspects of the technical paper fell under the headings of "observation" and "interpretation." Perhaps, not surprisingly, the students' use of evidenced claims was predominately under these headings (see Table 1). Thus, the engagement of the students in the task of using evidence was interpreted by them as aspects of describing observations and interpretations. Interestingly, the distinction between observation and interpretation is not a clean one for scientists. Indeed, Hanson (1958) and Kuhn (1970) suggest that all observation in science is interpretative. Thus, the relatively similar numbers of evidenced claims in the student papers under observations (n=27) and interpretations (n=35) may represent their struggle to identify what counted as 'observation' and 'interpretation' for this exercise, and in science generally. The written instructions indicating that for observations one is to "Discuss what you observed..." (Figure 7, line 460) and for interpretations one is to "Discuss what the data means..." (Figure 7, lines 467-468) may not have been readily distinguished by the students. This may indicate that some sophistication (however tacit) among the students that observations, as well as interpretations, need evidential support, and are not merely read from data inscriptions.

The range and variety of evidence used by the students also show a partial appropriation of the ways scientific writing was described to them. As shown in Figure 10, we considered the kinds of evidence, "stacked" these kinds from the most grounded in specifics to the most abstract, and then counted the distribution across all student papers. As presented in the teachers' discourse describing writing in science (Figures 5 & 7), the students were instructed to use their data inscriptions to make observations and through this use offer explanations as their interpretations. The bins with the highest frequencies in Figure 10 are "gestures to the graph," "descriptions of graphs," and "numerical values of graphs." While each of these represents different uses of evidence, the students can be seen as appropriately referring to their data sets in making their arguments. This use of evidence can be very grounded in particulars to support a specific claim, such as "The frequency of the fundamental was between 488 and 509 hertz, and its amplitude was 3.4" to rather vague invocations left to the reader to decipher, "The graphs show that the frequency of the rubber bands were almost exactly the same." The levels of evidence in this case are not measures of argument quality, but are intended to illustrate a range of evidence types provided by the students. Our "stacking" does not suggest that more or less abstract uses of evidence are more scientific or are a measure of student engagement in scientific discourse; all uses of evidence must be considered in the context of use given local conditions and purposes.

In reviewing the students' use of evidence we found that not all of the students engaged in the writing of science in the same way, nor with the same argumentation strength. There were instances where we saw the use of the scientific genre in form, but lacking much substance. The partial appropriation of the suggested discourse processes is perhaps not surprising as the students did not experience all the sociocultural practices typically found in scientific communities when facts are constructed in written forms. For example, in this cycle of activity, the students were not asked to complete an informal and formal peer review nor editorial review. But in scientific communities, the creation of the "stacked" claims leading to constructed facts is the product of long, rigorous, agonistic struggles. Only after such processes can claims be considered as potential new knowledge.

Thus, the students were given some opportunities to engage in the practices of science, and not others. Therefore, not all of their claims nor evidence would necessarily be considered correct from a canonical physics point of view.

For a final analysis of the students' papers, we considered some of the ways that the students interpreted their task and how this interpretation, while reasonable given the ways the tasks were framed through the oral and written discourses of the teachers, used a voice different than is typically found in an experimental scientific article. We found that in the introduction and conclusion sections of their papers, the students were most likely to consider audience issues and speak from and about personal experience. Consider the introductory remarks of the following student, Maria, as she orients a specific reader, i.e., "you:"

> "For our forth group project we decided to build a wooden guitar. In this paper you will read about the data that we collected from our instruments, what it's limits are, how we got the data, and where we got it. You will also read about our observations. After, we will write about what the data means." Maria

This practice was found in another student's introduction as well. Dennis, like Maria, built a guitar, but was in another student group:

> "Our group made a guitar for our project. We did the guitar because it was easy yet fun. I am writing this paper so the readers can know our results and how well our little guitar works. I am going to tell you, how we built our project." Dennis

Patricia, a member of yet another group, again used the second person to address the reader and inform the reader about what follows in the paper.

> "In this lab/project I have explored the world of sound and the relationship between patterns on paper to the actual noise heard by the human ear. In this paper I will take you through the process of exploring sound and disecting its scientific meaning. The instrument our group built was simple but effective. We took a scrap of wood and put nails in a wide "V" shape and connecting opposite nails with rubberbands. The sound that was predicted was similar to a harp or a guitar. In the next page or so you will hear our results and difficulties along with modifications done with our instrument in order to explore further into the purpose and intreging facts about sound." (Patricia)

The conclusion sections were similarly spiced with remarks about the experience of participating in the cycle of activity, about how students felt about the project tasks, and influences on their personal affinity toward the projects. Here are three examples from Laura, as well as from Ken and Eileen, who were members of the same group.

> "This project having to do with sound was very interesting to me because I do alot of things involving music and sound. This project was very fun, and it was interesting to see which pitches make which graphs and what frequencies you get with different pitches." Laura

"Over all this project was ok but you did not give us enough time to do it in. You did not give us enough time to type it or to build it. After the first day you assumed us to be done building it, when we finished over the week end. The project was ok just needed more time." Ken

"I have learned that it is very simple to use the graphs on the computer than on paper, and I have also learned that the guitar has a lot of different shapes, and a lot of different pitches. I think this is the best group project we ever did so far because, it was fun making the object and we had a lot of class time to accomplish them." Eileen

The reference to how the students related to the task and commentary on the tasks were not signaled in the oral and written instructions to the students. However, while this was a divergence from the particular scientific genre suggested to them, the teachers had established a practice of having the students write about the course (see Figure 6, "essays about the physics course"). Thus, the students took the writing of the conclusion as an opportunity to let the teachers know how they felt about the project, what they learned, and the difficulties they faced given the time constraints. Thus, the students were continuing a patterned practice consistent with this classroom community's norms and expectations (Santa Barbara Classroom Discourse Group, 1992; Zaharlick & Green, 1991).

Discussion

We have argued in this paper that discourse and interpretive processes are central to the creation of knowledge, both for scientists and students. By examining school science-in-the-making, we have identified how through patterned practices and concerted activity the teachers and students came to define interactionally what counted as science. In this section we discuss some theoretical issues and draw some implications from our study.

Our view of language use has been influenced by the work of the later Wittgenstein (1958). This view suggests that the meaning of a word, symbol, or construct is situationally defined by its use in a particular discourse practice (language game), that is, there is no essence of meaning, only how the signs and symbols fall into place relationally in particular instances of use. This suggests that ostensive definitions of complex constructs such as "observation" and "interpretation" and "evidence" represent only one sense of the use of these words, and that in each instance, this use is associated with a particular set of social practices. The range of use varies and as Wittgenstein (1958) described, "ostensive definition can be variously interpreted in every case" (p. 14, emphasis in original). Thus for the students in this study, the writing exercise can be interpreted as an opportunity to use scientific terminology, genres, and participate in social practices associated with science. Coming to understand the uses of data (in this case, sound waveforms) as evidence for a set of assertions (in this case, relationships of sound and physical changes) involves complex uses of language, meanings, and associated social practices. These practices must be learned through participation with more knowledgeable others (Vygotsky, 1962) and requires time and opportunities for both success and failure.

The difficulties posed by using domain specific knowledge in socially appropriate ways are formidable even for experienced members of the relevant communities of practice, as evidenced by the rejection rates of academic journals. In examining the students' work we attempted to understand what counted as evidence for them, how they used evidence in their writing, and how their claims and evidence resembled that of scientists. Our goal in this study was to examine student understanding, not to access the adequacy of their arguments. Thus, we did not attempt to pass judgment as to whether the students created logically coherent arguments, nor if their reasoning was formally consistent, nor did we hold them to any other normative standard with the goal of determining whether they understood the use of evidence or whether they were "rational." Learning how to use evidence in particular circumstances is not something we believe occurs in a short time period, nor does one achieve an understanding of evidence-use that is timeless and context-independent. In each situation, the interlocutor must read the social situation, make judgments about what counts in a particular community given the current situation, and draw from a repertoire of discourse processes and practices to attempt to act in socially appropriate ways (Gumperz, 1986; Heath, 1982; Heap, 1980, 1991).

Vygotsky and Wittgenstein both foreshadowed educational theory suggesting that students learn through legitimate participation with practitioners (Brown, Collins, & Duguid, 1989). Bazerman (1988) described the processes of how a neophyte, through scaffolding from others and progressively taking on the material and symbolic practices, comes to learn how to participate in a particular community. Through participation and engagement in the social practices of a community, learners come to use the situated language of the community and define for themselves what it means to become a scientist or mathematician (Brilliant-Mills, 1993). Our analysis of the students' technical papers suggested that there was only limited appropriation of scientific discourse. Some of the student papers maintained the form of the scientific genre suggested to them without using much evidence to support their assertions. Thus, the processes of school science-in-the-making were messy with successes and failures; some student texts created scientific sounding assertions, i.e., they "stacked" the claims in ways consistent with that of the disciplinary community (Latour, 1987). Other times students spoke from personal experience, or could be interpreted as engaging in procedural display, i.e., performing in the processes of studenting, rather than the substantive processes of knowledge construction (Bloome, Puro, & Theodorou, 1989). Thus, like the scientists in their laboratories (Knorr-Cetina, 1995), the students faced "interpretative flexibilities" and opened up the genre of scientific writing to negotiation. Given this range of appropriation of scientific discourse and the ways the students diverted from this "discourse," we now turn to the lessons learned by us through this experience and consider implications for the constraints facing students and teachers of science.

The variations in the students' appropriation of written scientific discourses suggests that there were missing elements in the instructional practices. For example, there was no instruction explicitly concerning scientific discourse and norms of the scientific community. Thus, while we believe that there is always interpretative flexibility in the appropriation of scientific practices, exposure to and examination of what counts as an empirical claim, a theoretical assertion, or a consistent argument, would have made the implicit knowledge of the teachers explicit to the students. The unpacking of scientific norms may be crucial if classroom activities aimed at reproducing authentic scientific contexts are to be successful at affording opportunities for students engaging in scientific discourses. While the two teachers of this class have extensive experience with practicing and studying science, their knowledge of the social practices of science were not a content theme of the course. Therefore, identification of these scientific practices was left to be induced by students and only some of the students did induce these practices, perhaps because of other experiences outside of school. Thus, the curricular move away from propositional knowledge of physics (e.g., formulas and definitions characterizing sound waves) to a focus on scientific processes (e.g., creating a scientific argument with data inscriptions produced by students with technologies) still required strategies for making these processes explicit to students.

The heterogeneous nature of the discourses of school science constructed by students, social mediators, texts and technologies contribute to some of the constraints we have identified to learning scientific practices over a set of ethnographic studies (Chen 1997, Kelly & Crawford, 1997). The lack of community-based accountability in the culture of the classroom has been a recurring theme. This issue is particularly difficult in school science where the agonistic argumentation of scientific communities may be unacceptable on normative grounds (e.g., such practices are potentially discriminatory, see Guzzetti, 1998 and subsequent commentaries, for an analysis of a gendered discourse practice using agonistic argumentation). Providing a supportive community that is willing to weigh the value of respective ideas, while maintaining value of speakers as individuals, remains an unfulfilled goal. As described by Bazerman (1988) scientists are required to hold their ideas up to public scrutiny. This scrutiny sometimes leads to highly contentious rhetorical attacks, sometimes expanding beyond epistemological to professional and personal attacks (see Collins (1985), for analysis of the deconstruction of a researcher, and subsequently, his proposed "high fluxes of gravity waves"). However, if public scrutiny is to be created in classrooms, it needs to be done in ways that students can maintain their individual integrity and still be able to discuss ideas in their own voices and present the evidence of their positions. Given the diversity in cognitive and social development and the culturally patterned ways of speaking that students bring to the classroom, this becomes a difficult and delicate affair. Furthermore, scientific argument, in the best case scenario, would be one of many competing goals of adolescents in schools who typically are concerned with peer culture and status, friendship groups, and other issues not directly related to learning science.

We do not believe any small set of prescriptions for teaching should be drawn from empirical research, given the diversity of situations and socially constructed contexts for learning. Nevertheless, if we were to teach this course again, we would attempt several strategies to help students learn to use evidence in science writing. One strategy would be to provide a more explicit discussion about our goals as teachers and how we see this task as an opportunity for them to learn about a particular genre of writing, that is, discussion around and about the processes of doing science in school. By better informing the students that we expected scientific writing to include justified claims and that we expected this to be achieved over the course of the academic year, the students may have been better able to engage in these practices. For example, we used Toulmin's layout of argument for analysis purposes, but not pedagogically. This model for creating an argument may have assisted the students in coming to understand what counted as scientific argument. Our second strategy follows from the discussions about learning science and concerns creating a coherent epistemological theme throughout the course. In this study and others we identified a range of activities with varying opportunities for learning. The change of frame across the various writing (see Figure 5) may not have offered sufficient coherence for students to understand how to write science in some ways under certain conditions. A third strategy would involve more modeling of the argumentation practices. Creating a substantive argument from a set of inscriptions is a complex social activity and the students would have probably been better served to see and hear a variety of examples from the teachers.

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Table 1

Distribution of evidenced claims for all student papers (n=22) across specified paper headings defined by technical writing genre.

Heading in technical paper	Number of evidenced claims
Introduction	2
Methods	0
Observation	27
Interpretation	35
Conclusion	1
Figures	1

Figure captions

Figure 1. Physics of Sound Cycle of Activity:
Sources and types of educational research data

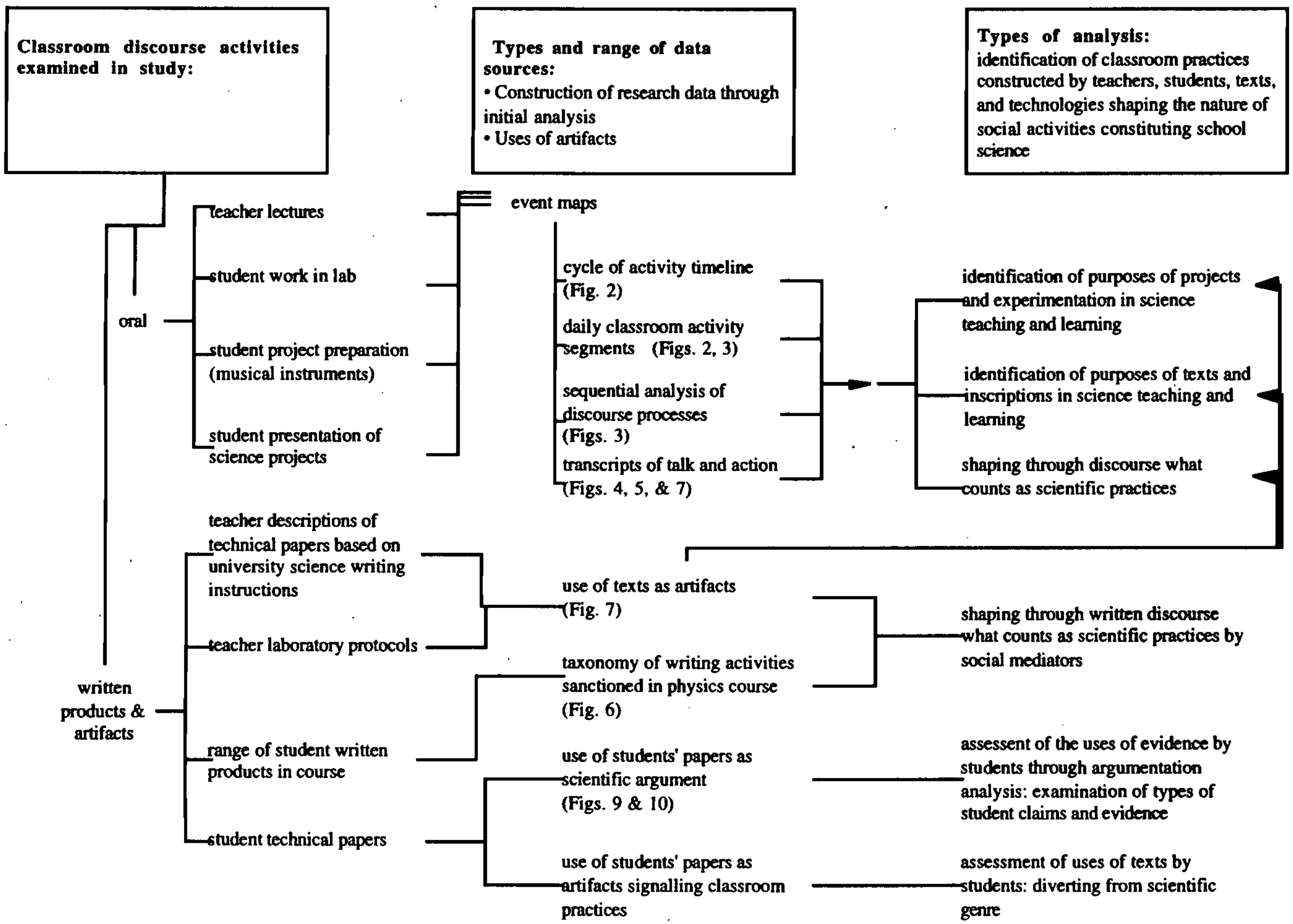

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Figure 2. The Musical Instruments Project situated in and across time

TIMELINE OF THE OVERALL ETHNOGRAPHY		
Academic Year One	**Academic Year Two**	Academic Year Three

CONCEPTUAL PHYSICS: SCIENCE PROJECTS							
Project	1	2	3	**4**	5	6	7
Dates	09/07/95-09/29/95	10/02/95-10/23/95	10/26/95-11/02/95	**11/06/95-11/21/95**	11/29/95-12/15/95	12/18/95-12/22/95	01/08/96-01/22/96
Project topic	Catapult	Circular Motion Space Travel Projectile Motion	Solar Energy	**Musical Instruments**	Optics	History of the Atom	Museum Project
Conceptual theme	Mechanics	Application of mechanics	Thermo-dynamics	**Sound waves**	Optics	Atomic energy	Enacted science

MUSICAL INSTRUMENTS PROJECT: KEY EVENTS									
11/06/95	11/07/95	11/08/95	11/09/95	11/13/95	11/15/95	11/16/95	11/17/95	11/20/95	11/21/95
*Simple Harmonic Motion lecture *Pendulum lab *Discussion of graphs	*Graphing (whole class; groups) *Wave lecture *Film on waves	*Wave lecture *Sound lab: tuning fork & voice *Demo of FFT *Discussion of labs & projects	*FFT lecture with demo *Sound lab: consonants & vowels	*Light lecture *Sound lab: fundamental & harmonics *Presentation of lab data	*Review of test *Chapter test ***Intro of Musical Instrument project** *Discussion of projects	***Intro to writing technical papers** *Project time: construction of musical instruments	*Project time: construction of instruments; data collection)	*Project time: data collection & measurements)	*Preparation for presentation *Student presentations of musical instruments *Optics lecture

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Figure 3. Structuration table representing the "Introduction of Musical Instruments project" phase of activity

Time	Sequence units	Notes and comments
00:55:03	Passing out project instructions	*Classroom Teacher (CT) and Teacher/researcher (TR) pass out the instruction sheets to the class*
00:56:38	Discussion of scheduling project after the labs	*TR describes to students that they (the teachers) scheduled this project to be conducted after the relevant labs, so that the students could focus strictly on this assignment. In the previous projects, lab work were interspersed throughout the cycle of activity.*
00:56:56	Keeping a record of the group's activities	*TR goes over the various parts on the instruction sheet; informs students that they need to keep a record of their group's activities*
00:57:10	PD: Time constraints	*Students complain about the time allotted for the projects*
00:58:49	Keeping a record of the group's activities	*TR returns to the record of activities*
00:59:03	Collecting information	*Students are instructed to collect information; TR suggests the Internet and the library*
00:59:16	Constructing the instrument	*Students are informed that they need to build the actual instrument*
00:59:35	Conducting the experiment	*Students are informed that they need to conduct the experiment with the use of the computer (program and instruments that they used in the previous sound labs)*
00:59:53	Changing the instrument	*Students are informed that they need to change the instrument for the purposes of this project*
01:01:20	Writing the paper	*Students have to write a paper; TR tells students that more information about that will be given at a later time*
01:02:03	PD: Opportunity for extra credit	*Student asks if they will be given any opportunities for getting extra credit on this project*
01:02:15	Summary of project tasks	*TR reiterates the project tasks from the instruction sheets*
01:02:15	Strategies for starting project	*CT makes suggestions for how to get started on the project.*

Figure 4. Transcript of teacher discourse relating to the suggested processes of the musical instruments project.

Line	Message unit
100	**TR:** let's quickly go over what we want you to do
101	the first one I mentioned before
102	is to keep a record *[students interrupt with inaudible comments]*
103	**CT:** uh
104	one person
105	at a time
106	please
107	**TR:** okay part two
108	is to look around for information on the internet
109	and
110	the library
111	that's what you'll start today
112	okay
113	so you can look around and see if there's
114	like what you did for the solar energy project
115	see what kind of research you can find on the internet
116	as a group
117	the third piece
118	is you actually build the instrument that your group
119	is gonna have
120	and everyone should contribute to that
121	construction
122	kay you all come to class
123	to do it
124	you can bring things in here
125	and it can be very simple
126	kay?
127	it doesn't have to be
128	um
129	you know
130	a
131	a very sophisticated instrument
132	so (xxxx)
133	**TR:** okay
134	part four is really important
135	you need t-to
136	conduct experiments
137	okay?
138	with the
139	microcomputer like we were doing on Monday
140	and you're gonna get graphs like this *[holds up sheet of paper to the class]*
141	that you just saw
142	alright?
143	and what you wanna do
144	is then
145	is
146	is to get information about your instrument
147	okay?
148	in part five
149	you're gonna change something about your instrument
150	so for instance
151	Kyle's group is making a flute
152	out of bamboo
153	one thing you can do is to change the length
154	add different holes
155	whatever
156	you should change things in some way
157	and then
158	go back and re-
159	record the data again

Figure 5. Transcript of teacher discourse reiterating and orienting to task.

Line	Message unit	Line	Message unit
200	**CT:** we're asking you to do	246	before holiday
201	a number of different things	247	so
202	for this project	248	many students
203	and	249	some students
204	there's not	250	won't be here
205	a lot of time	251	that day
206	so let's	252	so that's
207	let's	253	really not a good day
208	let's	254	to do particular projects
209	break it down	255	so
210	and see	256	we'll count on
211	exactly what you need to do	257	having it due
212	and try to set up	258	next Tuesday
213	a time table to do it	259	kay now
214	you're gonna hafta	260	we'll have a lot of time in class
215	the first thing that you're gonna have to do	261	between now
216	is to	262	and next
217	select an instrument	263	Tuesday
218	the next thing you're gonna hafta do is	264	to do it
219	is build it	265	okay
220	or make it	266	so let's
221	the next thing you're gonna hafta do	267	let's
222	is	268	look at
223	test it out	269	go to the time table
224	and	270	we can
225	the next thing you hafta do is	271	okay
226	write a paper about it	272	if you're gonna have to
227	okay	273	build it
228	so those are four	274	to test it
229	major	275	you need to know
230	activities	276	what it is pretty quickly
231	that are part of the same	277	okay?
232	project	278	so
233	and	279	the first order of business
234	it it	280	would be
235	itta	281	when you meet with your groups today
236	be due	282	before you do anything
237	on next	283	just discuss your ideas
238	Tuesday	284	on what
239	kay	285	what
240	that's	286	may be an issue
241	**Std:** (inaudible)	287	you may
242	Tuesday or Wednesday?	288	have an idea already
243	**CT:** Tuesday	289	and you don't have to do any searching
244	Wednesday	290	in the library or the internet
245	is the last day	291	okay?

Figure 5. (Con't). Transcript of teacher discourse reiterating and orienting to task.

Line	Message unit	Line	Message unit
292	or you may not	303	5 or 6 minutes
293	have an idea	304	or maybe 10 minutes
294	in which you case	305	and then chose a representative
295	you can do	306	from that group to=
296	a search today	307	**Std:** =how 'bout
297	on the internet	308	**CT:** =to tell us
298	so I think	309	yer
299	maybe the first thing that we should do today	310	what
300	is go back in your groups	311	your ideas are
301	and discuss it	312	okay?
302	for about		

Figure 6. Taxonomic analysis of writing activities sanctioned in conceptual physics

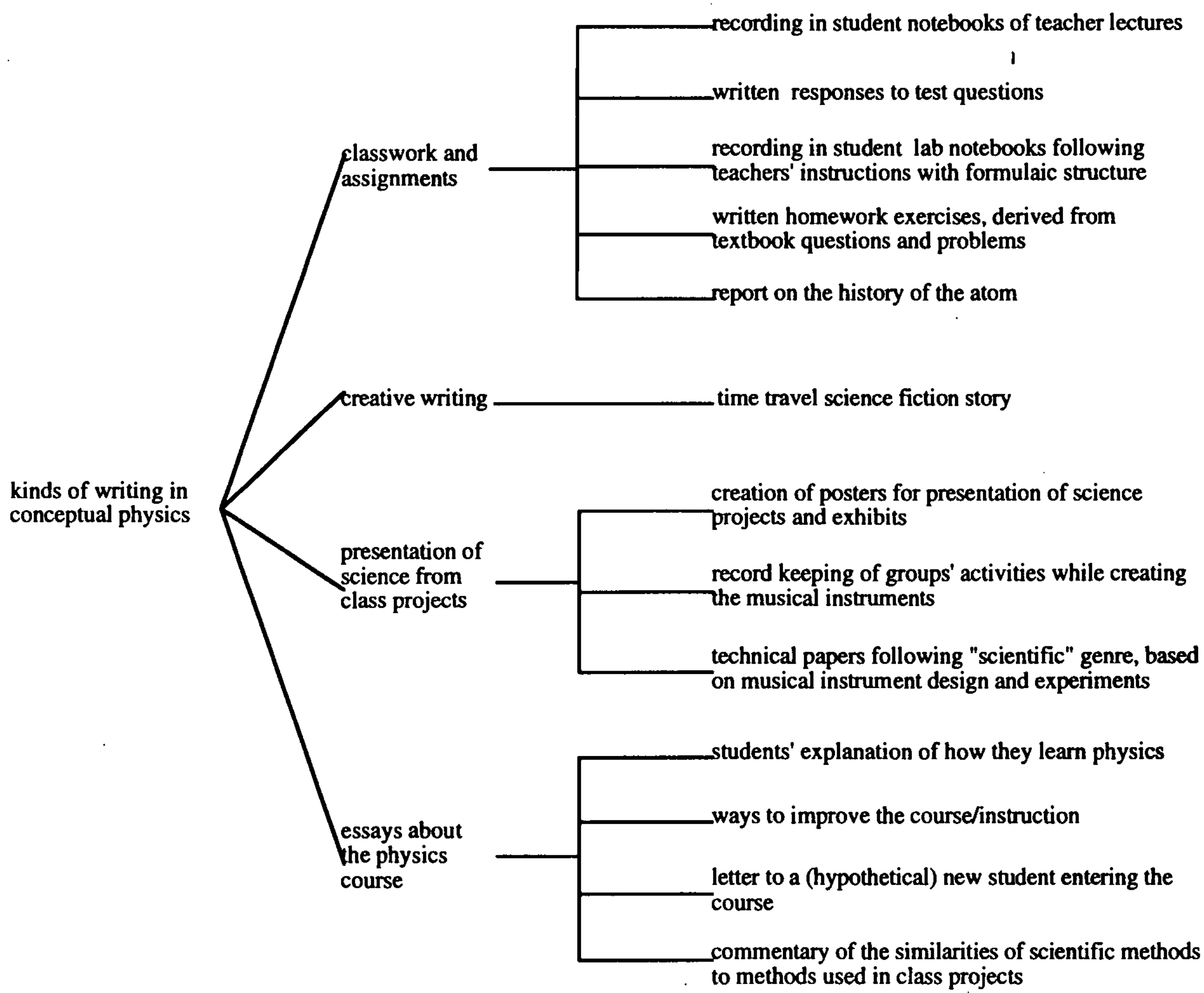

Figure 7: Framing the writing of the technical paper with oral and written discourse

Oral discourse: Talking text into classroom life	**Written discourse: How to Write a Technical Paper**
Orientation: **Teacher/researcher (TR):** it's very important/for scientists/engineers/ and other/people who're working (in) professions/to be able to/write well/and differently in/the technical sense/and/writing about/um/things that are not/say=um= **Student:** =do we stay in our group/or= **TR:** =just let me finish this sentence/ kay/(right)/fiction/or/uh/what/a description of a/biography or something like that/okay?	Orientation: Technical writing is the "stock and trade" of scientists and engineers (and most professions). They write to get money for their work, to sell their products, to publish in learned journals, to persuade others, and a myriad of other pursuits. In this course you are being asked to learn to think like a scientist by going through the complete process of designing your experiments, collecting data, thinking and pondering about it, and writing up your results. As with many of your labs, you will use real data to arrive at your conclusions.
General writing tips: **TR:** now/this says here/general writing tips you can read through that/ *[TR looks down at instruction sheet]*	General writing tips: 1) The paper should be organized carefully. Follow the outline below. 2) Each section of your paper will be composed of paragraphs. Each paragraph should begin with a topic sentence which states the point you will make in that paragraph. Every sentence after that should support the topic sentence. 3) Make your sentences simple, but vary their length to make the paper interesting. 4) Avoid the passive tense. It is boring. An example of the passive tense is: "It was shown that .... " An example of the active tense is "I have shown that .... " 5) Avoid contractions. These are for more informal writing. Say "can not" instead of can't."
Presentation **TR:** and then your presentation of your paper/ you can either type it/or/ handwrite it neat (enough)/ either way is okay/	Presentation Your paper should be clearly typed or clearly hand written and thoroughly proofread. Spelling mistakes are not acceptable. Double space the text and use either 10 or 12 point text size.

Figure 7 (con't): Framing the Writing of the technical paper with oral and written discourse

Headings

TR:
on the back is/we give you/
all the details about what you need to
include/kay?/
and you'll notice it's not a lot different/
than what you're doing in your/your lab
reports/okay?
things like/
(the) introduction/you explain what you're/
what you're going to be doing/
so the person who's reading it can/
understand what it's about

the methods you do here/the instruments
for data collection/things like that/it'll be
very short you have/(could use) things in
class/please explain what you're
using/okay?
observations of what you observed/from
the data you are collecting/okay?/you can
use figures here

TR:
in other words/you can do these/tests/
of your data/and print it/print it on/
it'll go out on the printer
[TR points toward the adjacent room and
explains details of receiving computer
print-out]

data is whose/
and you just take that and put it right up
with your technical report/
so that'll be your figures/alright?/
your interpretations/discuss what that data
means/so for example/you look at your
wave form/you can figure out things like/
frequency/how that's related to pitch/
how it's related to the change in your/
um/your modification of your instrument/
and then you write up your conclusions/
kay?/

Headings

Technical writing follows a specific format. this format varies, depending on the subject and requirements for publication. But, there are common features to all formats. Follow the format described below for your musical instrument paper.

Introduction: Orient the reader. Tell her or him what you are going to say. Answer the question: Why are you writing this paper? This is an important part of the paper because it will tell the reader whether you have something to say or not.

Methods: What instruments of data collection did you use? What are their limitations? Tell the reader how and where you got the data.

Observations: Discuss what you observed. It is not necessary to talk about conclusions or reasoning here. Just stick to what you observed. You may want to use Figures represent your data (see below under Using Figures).

Interpretation: Discuss what the data means. Here is where you take your individual observations and use your experience, insight, and knowledge to explain them. Your may want to make sketches to explain a point. It is important that you reason with evidence; use your observations in your explanations.

In scientific fields other researchers may want to use your results. Therefore, it is important to be open and honest in reporting.

Conclusions: Here you summarize your findings without carefully explaining your logic or reasoning.

Figure 7 (con't): Framing the Writing of the technical paper with oral and written discourse

Headings (con't)

[After short sequences concerning the length of the papers and the assistance offered by the teachers, TR exaplins the "main idea."]

And the main idea now is that you're going to be using the data you collect in class and use that as evidence for your interpretations. Alright?

Headings (con't)

Using Figures: The old cliché that says a picture is worth a thousand words is especially true for technical writing. Any time you can illustrate a point with a picture or sketch, the clarity of the presentation is enhanced many times. Label you figures and reference them in the text of your paper. For example, label might your first waveform "Figure 1: waveform of sound produced by drum with low tension." In the paragraph, you reference the waveform data as follows: "as shown in Figure 1...."

Figure 8. Sound waveform inscription with associated Fast Fourier Transform (FFT) hypertext.

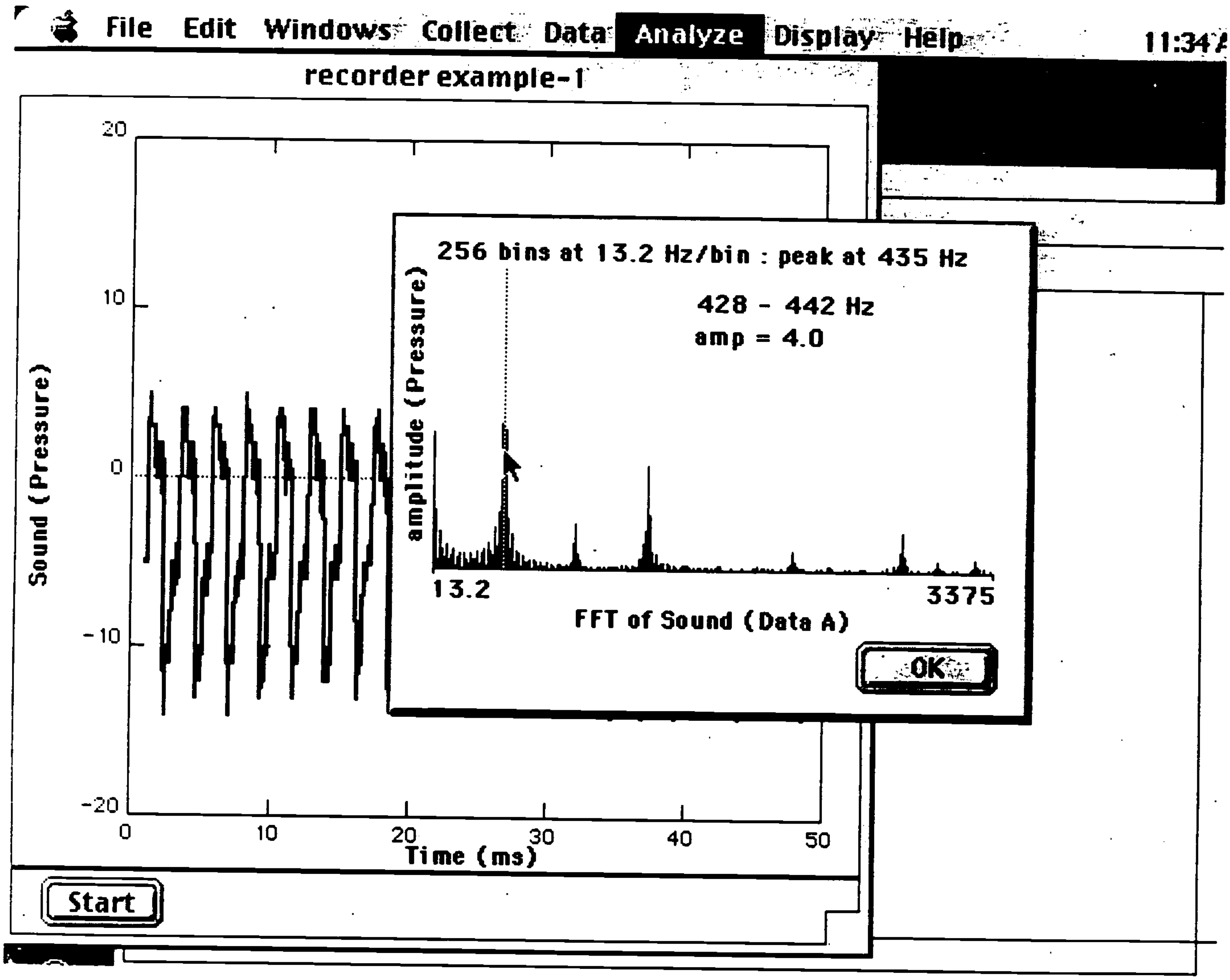

Figure 9: Kinds of evidenced claims, typical examples and distribution across student papers (n=27).

	Kinds of Evidenced Claim	n	Typical Example
high induction	Tying representation and physics construct	13	"In the graphs there are large spikes, medium peaks, and small waves. Each one represents the frequency of sound."
	Relating physical phenomenon to physics construct	31	"It seems the harder we plucked the rubber bands the more sound and the higher the frequency."
	Specifying physics construct with measured values	1	"For example we were not aware that there did not necessarily have to be a harmonic frequency like our Data "B" has no harmonic frequency but, we did get a fundamental frequency of 271-293 Hz and an amplitude of 7.6 which was the loudest of the strands and had the lowest tension, as where Data "A" does have one (184-206 and an amplitude of 6.9 and a fundamental frequency of 54.2-75.9 with an amplitude of 5.9.)."
	Relating aspects of representations	6	"I also found that in string one that the amp of the fundamental and the amp of the harmonic are one apart 5.9 to 6.9."
	Tying physical phenomenon with representation	5	"The vibration was a low tone which was recorded by the computer and graphed like so: the lines were in a constant pattern of up, down but between the intervals there constant ridges which showed the vibration between peaks."
	Tying representation to physical instrument	4	"Graph B shows our drum altered with 3 pieces of paper wadded up inside and no plastic lid on top, only wax paper.
	Reporting measured values	6	"The frequency of the fundamental was between 488 and 509 hertz, and its amplitude was 3.4."
	Relating phenomenon with its consequence	2	"If you have two pieces of string and one is held tightly (high tension), and the other very loose (low tension), then when you hit the string with a stick, the tight one will send waves up and down the string quickly and the loose one will send low, slow waves.
	Relating data collection instruments with accuracy of measurements	1	"The instruments used did have some inherent limitations which affected the accuracy of the results in this experiment however."
low induction	Describing characteristics of an element of the instrument	4	"We had four different drums, all of different sizes, to make a variance of noises."

Other Kinds of Evidenced Claims (not "stacked"):	n	Typical Example
Commenting on project tasks	4	"I don't think that we had enough time to do this project."
Addressing prescribed sections of the technical paper	3	"This are the observations we saw. The graphs show it, down below."

Figure 10: Kinds of evidence typical examples. and distribution across student papers (n=27).

	Kinds of Evidence	n	Typical Example
Abstract	Experiment	1	"Doing this experiment proved that the wax paper had a very low tension because of the loose material that it was make of."
	Previous claims	2	"Well,as I said before, both figures have got there own waveforms."
	Construct of physics	1	"We applied the physics of tension to our project and conclude that the sound is better of the drum with less tension."
	Perception of physical sound waves	1	"The faint noise of this proves that the wood is to thick to act as a sounding board and magnify the sound."
	Gestures to graphs	21	"The graphs show that the frequency of the rubber bands were almost exactly the same."
	Methods employing computer functionality	3	"The instruments used did have some inherent limitations which affected the accuracy of the results in this experiment however. For instance when the computer interpreted the frequencies into numerical equivalents, they were rounded to the nearest whole number. Therefore, this number could reflect a range of what the frequencies might be."
	Descriptions of graphs	28	"The small drum had all of the sound wavelengths right together and the big drum had all of the wavelengths more spaced out."
	Explicit reference to and descriptions of graphs	5	"As shown in Figure 1 on the graph that is on the other page, it doesn't repeat itself, meaning it is not playing the same tune all of the time that the shortest rubberband was struck or played."
	Design issues	2	"The drum lid had more tension because the lid was harder, and the bouncy ball bounced off the lid more. This proved that the wax paper had very low tension because the material was more loose."
	Schematic drawings of the instrument	1	"Figure 1 shows the guitar with three rubberbands, they are the shortest. With the rubberbands the sound isn't very loud, but it does make a sound, but because they are short their sound isn't very high. In Figure 2 the guitars' shown with two rubberbands, they are longer than the other three. They make a louder sound because they are more stretched. Figure 3 shows the guitar all together with what looks like three short rubberbands."
Grounded in specifics & particulars	Numerical values of graphs	14	"The frequency of the fundamental was between 488 and 509 hertz, and its amplitude was 3.4."

Other Kinds of Evidence (not "stacked")	n	Typical Example
Analysis of time allocated for projects' tasks	1	"On the catapult project you gave us three weeks, 15 class days to work on it. 21 days including weekends. So I don't think that it's fair that we didn't get enough time to do this project."

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